Determining the Probability of Pesticide Exposures Among Migrant Farmworkers: Results From a Feasibility Study

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Background *Migrant and seasonal farmworkers are exposed to pesticides through their work with crops and livestock. Because workers are usually unaware of the pesticides applied, specific pesticide exposures cannot be determined by interviews. We conducted a study to determine the feasibility of identifying probable pesticide exposures based on work histories.*

Methods *The study included 162 farm workers in seven states. Interviewers obtained a lifetime work history including the crops, tasks, months, and locations worked. We investigated the availability of survey data on pesticide use for crops and livestock in the seven pilot states. Probabilities of use for pesticide types (herbicides, insecticides, fungicides, etc.) and specific chemicals were calculated from the available data for two farm workers. The work histories were chosen to illustrate how the quality of the pesticide use information varied across crops, states, and years.*

Results *For most vegetable and fruit crops there were regional pesticide use data in the late 1970s, no data in the 1980s, and state-specific data every other year in the 1990s. Annual use surveys for cotton and potatoes began in the late 1980s. For a few crops, including asparagus, broccoli, lettuce, strawberries, plums, and Christmas trees, there were no federal data or data from the seven states before the 1990s.*

Conclusions *We conclude that identifying probable pesticide exposures is feasible in some locations. However, the lack of pesticide use data before the 1990s for many crops will limit the quality of historic exposure assessment for most workers.* Am. J. Ind. Med. 40:538–553, 2001. *Published 2001 Wiley-Liss, Inc.*†

KEY WORDS: agriculture; migrant workers; pesticides; exposure assessment

INTRODUCTION

Most of the labor-intensive farm work in the United States is done by migrant or seasonal farmworkers and their children, who may comprise up to 25% of the workforce during summer harvests [Moses et al., 1993]. The health effects, particularly chronic illnesses, have not been well studied among this group of workers, in spite of the potential for high cumulative exposures to pesticides. Exposure to pesticides has been associated with increased risks of certain cancers among farmers and other pesticide workers [Zahm et al., 1997] as well as other chronic and acute health effects [Keifer, 1997]. Most cancer epidemiology studies of agricultural populations have included only farm owners and operators, whereas little is known about the occurrence of cancer and other chronic health effects among migrant farmworkers [Zahm and Blair, 1993].

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Whereas some migrant farmworkers are exposed to pesticides through jobs as pesticide applicators, more often they are exposed while engaged in tasks such as harvesting, weeding, or pruning fruits, vegetables, and other high-value crops. These crops are normally treated multiple times in a season with a wide array of pesticides including insecticides, herbicides, and fungicides. Work with these crops can result in high to moderate exposure [Nigg et al., 1990] sometimes exceeding that for pesticide applicators [Loewenherz et al., 1997]. Further, the duration of exposure may be substantially greater for farmworkers compared with farm pesticide applicators, resulting in high cumulative exposures [Fenske, 1997]. Pesticide exposures for migrant workers can be exacerbated due to a lack of facilities for handwashing, showering, and laundering contaminated clothing [Meister, 1991; Moses et al., 1993]. Additional exposure of farmworkers and their families occurs from contaminated clothing brought into the home and from spray drift from nearby fields [Camann et al., 1995; Simcox et al., 1995; Loewenherz et al., 1997].

Questionnaires have been used to identify and quantify exposure to pesticides among farmers and others directly involved in applying pesticides [Zahm et al., 1990; Cantor et al., 1992; Blair et al., 1997]. Typically, these groups are able to identify specific chemicals they have handled and describe the duration or intensity of use. However, direct questioning of farmworkers concerning exposure generally is not useful because they usually do not apply the pesticides themselves and often are not aware of the specific pesticides applied by others to the field or orchards in which they work [Mentzer and Villalba, 1988]. Therefore, other methods are needed to assess exposures to farmworkers.

A series of pilot projects was initiated in seven states in the U.S. to determine the feasibility of studying cancer and other chronic health risks among migrant farmworkers. In one project, a questionnaire was developed and administered that used calendars and icons of life events, crops, and tasks, to aid in obtaining a lifetime work history [Zahm et al., 2001, this issue]. In this paper, we describe the major crops and tasks reported by the farmworkers and the relevant pesticide surveys and other data that could be used to identify the probable pesticide exposure of these workers. We also present two work histories from the pilot project to illustrate how the pesticide use data might be used to identify probable pesticide exposures.

MATERIALS AND METHODS

Study Population

Migrant farmworkers were interviewed about their work histories in seven states—California, Colorado, Florida, Montana, Texas, Washington, Wisconsin. The states were chosen because of the presence of migrant workers and the availability of collaborators who had worked on migrant worker health issues. We selected samples of older retired workers as well as active workers, who tended to be younger from populations at migrant health clinics, social service agencies, community centers, or other agencies. There were two centers in California and Wisconsin and one center in each of the other states. Nine men and nine women were interviewed at each center.

Interviews

Interviews were conducted in 1996 with a total of 162 workers (81 men, 81 women) who ranged in age from 17 to 79 years (average: 42 years) and who were currently or formerly employed as migrant farmworkers. The interviews were conducted in English or Spanish depending on the respondent's language preference. The questionnaire used calendars and icons (small pictures or graphics that designated crops, tasks, and life events) to aid in recording lifetime work histories starting with the most recent job [Zahm et al., this issue]. The calendar/icon method resulted in a more detailed work history compared with the traditional questionnaire approach [Engel et al., 2001, this issue].

For each job, workers were asked about the location where they worked, the month and year, type of crop, tasks performed (e.g., harvesting, pruning), and number of days they spent doing the task. They were asked how often they worked in fields while or soon after pesticides were applied and if the respondent reported that they themselves applied pesticides to a crop, they were asked to name the specific pesticide that they handled. The workers were also asked general questions about sanitary conditions and work practices that could affect their exposure to pesticides, including the availability of clean water for washing their hands, bathing, and laundering clothes, the type of work clothes they wore, and the frequency of washing work clothes. They were also asked if they used pesticides in their home or garden.

Work History Summaries

Crops that accounted for the top 75% of the specific agricultural jobs reported by the farmworkers in each of the seven states [hereafter called "major crops"] were identified. We counted cattle ranching as a "crop" but not nonspecific crops identified as "other crops" or "other fruits." The task reported most frequently for each state–crop combination, and the median number of days spent doing the task after excluding those listed as "general farm work" was determined. The first year, last year, and median year worked for each of the major crops were noted.

Sources of Information About Pesticide Use

We investigated the availability of national, regional, and state data on pesticide use for the major crops reported by farmworkers in this pilot study.

Federal pesticide use surveys

The U.S. Department of Agriculture [USDA], the main federal agency responsible for collecting information on pesticide use on crops and livestock in the United States, conducted the first comprehensive survey of pesticide use by farmers in 1964. Farmers and growers were asked to provide crop-specific information on pesticide use. Mail surveys were conducted in 1964 [Eichers et al., 1968], 1966 [Fox et al., 1968; Eichers et al., 1970], and 1971 [Andrilenas, 1974], whereas personal interviews were conducted in 1976 [Eichers et al., 1978], the late 1970s, 1982 [USDA, 1982; Duffy, 1983], and from the late 1980s to the present. All surveys were based on a probability sample of farms or growers, stratified by farm size and often excluded small farm operations. The sampling frame for the surveys in 1964, 1966, 1971, and 1976, included all 48 contiguous states, whereas the surveys thereafter included only the major producing states for the crops surveyed. The USDA surveys that included one or more of the major crops reported by farmworkers in this study (various fruits and vegetables, cotton, sugar beets, cattle) are summarized in the Appendix.

In the 1964, 1966, and 1971 surveys, pesticide use was reported for specific field crops (corn, wheat, sorghum, soybeans, cotton, tobacco, hay), potatoes, apples, and citrus fruits. Use data for sugar beets were also reported in the 1966 survey. Data for other crops were combined and reported for "other deciduous fruit," "other fruits," "other vegetables," and "other field crops." The 1976 and 1982 surveys included pesticide use information only for field crops and pasture/rangeland. These five surveys also collected data on livestock insecticides. Crop-specific surveys were conducted for citrus in 1977 [Haydu, 1981], deciduous fruits in 1978 [Webb, 1981], and vegetables, fall potatoes, and cotton in 1979 [McDowell et al., 1982; Rich, 1982; Parks, 1983; Ferguson, 1984].

In the late 1980s, the data collection effort for crop pesticides became more frequent. Annual surveys of pesticide use on field crops began in 1986. The 1986 and 1987 surveys included corn, cotton, soybeans, and wheat. Fall potatoes and rice were added in 1988. The USDA began alternating year surveys of vegetables (including melons and strawberries) in 1990 and fruits (including nuts and berries) in 1991 (USDA National Agricultural Statistics Service website).

All of the USDA surveys provided some type of crop-specific usage data for individual pesticides or chemical classes of pesticides. The 1964, 1966, 1971, 1976, and 1982 surveys provided only national estimates (acres treated, pounds applied) for individual herbicides, insecticides, petroleum, miticides, fumigants, defoliants/desiccants, and plant growth regulators. However, usage data was grouped by type of pesticide (herbicides, insecticides, petroleum, others) and also reported for 10 US regions.

State-specific estimates of pesticide use were reported in the annual field crop surveys beginning in 1986 and in the fruits and vegetables surveys in the 1990s. The 1986–1989 field crop surveys only provided information on the acres treated with a pesticide, although since 1990, application rate data and total pounds applied were also obtained. The fruits and vegetables surveys in the 1990s provide estimates of crop-specific pesticide use including the acres treated, number of applications, application rates, and pounds of active ingredient applied.

State data sources

All of the seven pilot states had some pesticide use data in addition to the USDA surveys; however, most states started these data collection efforts only recently.

State pesticide use data are most comprehensive for California, which has had some type of mandatory reporting for agricultural pesticides since the 1950s [California Department of Pesticide Regulation website]. Applicators were required to report specific pesticide use by crop to the county agricultural commissioner for compilation by the California Department of Food and Agriculture. Beginning in 1969, information about restricted-use pesticides was made public. Until 1990, these reports were the only comprehensive information on pesticide use in California besides the USDA surveys. In 1990, a new law required growers to report all pesticide use on crops on a monthly basis, including the pesticide name and manufacturer, crop treated, the location (Public Land Survey section—approximately one square mile), the date and time of application, acres treated, method of application, and application rates. These data were first made available as paper reports; they are now currently available as electronic files (California Department of Pesticide Regulation website; California Pesticide Impact Assessment Program, website).

Surveys of agricultural pesticide use on all major crops were conducted in Colorado in 1989 and 1992 [Bohmont, 1993]. Commercial applicators, extension agents, and other knowledgeable individuals were asked to estimate the percent of acres treated, number of applications, and the average application rate. Crops surveyed included alfalfa hay, sugar beets, vegetables including potatoes and onions, and some fruits. Colorado State University Extension specialists published pesticide use recommendation reports for some Colorado crops [Cranshaw et al., 1990], but relied on Washington state pesticide recommendation reports for grapes and on Nebraska reports for livestock insecticides (S. McDonald, personal communication).

USDA survey data for pesticide use on citrus and vegetables in Florida have been published as separate reports since 1995 [Florida Agricultural Statistics Service, 1995]. Additional survey information was collected for strawberries [Aerts and Nesheim, 1997], cotton [Aerts et al., 1998], and ornamental plants [Hodges et al., 1997] under the National Agricultural Pesticide Impact Assessment Program of USDA. These reports have additional information on the methods and timing of pesticides applications, pesticide formulations, and integrated pest management practices.

In Montana, a survey of pesticide use on sugar beets was conducted in 1990 [Johnson, 1992]. A field crop survey in 1987 also included sugar beets and a survey of pesticide use on sugar beets for 1999 crop year was recently completed (R. Petroff, personal communication). Pesticide use recommendation reports were published from the 1950s through the 1990s for Montana and neighboring states, and have been summarized for sugar beets, cherries, alfalfa, and cattle, for 5 year time periods from 1955 through 1995 [Lenssen and Blodgett, 1996]. Pesticides commonly used on major crops in Montana are also contained in a report by the Montana Migrant and Seasonal Farmworker Council [1995], which lists the major pesticides used in the early 1990s and the usual timing of applications. Montana currently requires all commercial and government applicators to report pesticide use every five years. More limited reporting of agricultural pesticide use is required for private applicators. Pesticide dealers are now required to report their pesticide sales.

The pesticide use data for Texas consist almost exclusively of USDA efforts that included Texas. A separate survey of cotton growers was conducted to determine pesticide use and pest management practices in 1994 [Smith et al., 1996] under the USDA National Agricultural Pesticide Impact Assessment Program. As part of a recent effort to study health along the Texas–Mexico border, the Texas Department of Agriculture conducted a survey of pesticide sales in 1992 for three border counties. Data on the top 20 pesticides were published in a recent report [Akland and Schumacher, 1998].

The USDA survey data from the 1990s for asparagus, tree fruits, and other crops in Washington has been summarized [Washington Agricultural Statistics Service website]; however, there have been no additional statewide pesticide use surveys for these crops. Annual pesticide use recommendations have been published since 1951 for tree fruits [Washington State University, 1951–1998] and since 1974 for grapes [Washington State University 1974–1980, 1981–1998]. No pesticide use survey data are available for hops; however, information about the pesticides currently used on hops and estimates of the acres treated have been described in USDA Office of Pest Management Policy website.

Pesticide use surveys for selected vegetable, fruit, and field crops were conducted in Wisconsin for the growing seasons in 1985, 1990, 1992, 1994, and 1996 [Wisconsin Agricultural Statistics Service 1986; 1991; 1997]. Information on the acres treated and application rates for specific pesticides was collected using in person or telephone interviews from a sample of farmers and growers from nine regions of Wisconsin. There is little information about pesticide use on Christmas trees with the exception of one survey conducted in 1991 [Wisconsin Agricultural Statistics Service, 1992]. Wisconsin Agricultural Extension Service pesticide recommendations for cucumbers and Christmas trees were summarized in a recent report [Mize, 1995].

Other data sources for pesticide use or pest management practices

Our review of pesticide use data only included published reports and data in the public domain. Other sources of pesticide use information include proprietary data from market research firms, user groups, and the pesticide industry. These databases have been used by the Environmental Protection Agency in its assessment of industry sales of pesticides; however, crop-specific data on individual pesticides used are not routinely published [Aspelin, 1999a]. It is possible that with the permission of the owners, these data might be used in the future (A. Aspelin, personal communication 1999b).

Information from publicly-available pesticide use surveys as well as proprietary databases available to the EPA, is currently being compiled into a comprehensive review of pesticide use trends by economic sector [Aspelin, 1999a]. This monograph summarizes estimated trends in pesticide use for agricultural and other purposes from the 1930s through the 1990s.

Currently, as a requirement of the Food Quality and Protection Act of 1996, a database is being compiled of current cultural and pesticide use practices for many crops grown for human consumption [USDA Office of Pest Management Policy website]. These "crop profiles" usually provide information on cultural practices including timing of tasks and pesticide applications, and usual pesticides applied. Crop profiles are currently available, in review, or proposed for all the major crops in this study except for cotton in California, sugar beets in Montana, cantaloupe in Texas, and Christmas trees and cucumbers in Wisconsin.

Pesticide Use Probabilities

The pesticide use data can be used to identify possible pesticides to which workers may have been exposed. We selected two workers' agricultural work histories to illustrate our method of calculating pesticide use probabilities; they included crops, states, and years for which the quality of the pesticide use information varied. For each crop, we calculated the probability that a general type of pesticide (herbicide, insecticide, fungicide, others) and individual pesticide active ingredient was used in the state and year reported. We also rated our confidence in the probability estimates.

The probability that a pesticide was ever applied to a crop was estimated by dividing the number of acres treated one or more times with the pesticide by the total acres planted in the crop. The probability estimates were categorized into five levels: level 1, $<10\%$; level 2, 10–39%; level 3, 40–69%; level 4, 70–89%, level 5, $\geq 90\%$. Because pesticide use data were not available for every year and state, we calculated probabilities by using the best data available and assigned a confidence level based on the degree of extrapolation of the data. The USDA pesticide survey data in the 1990s indicated that use typically did not change more than one probability category over a 5-year period. We used the closest year of pesticide use data up to a maximum of 10 years from the work history year. If state data were not available we used regional estimates of use or use data from another state in the same region. If state or regional data were not available, we used national estimates of pesticide use.

We rated the confidence that we had in the probability estimate on a scale of 1-4. A score of 4 (high confidence) indicated that the probability was calculated from crop-specific pesticide use data for the state worked within 5 years of the year worked. A score of 3 (medium-high confidence) indicated that the probability was calculated from regional data or data from another state in the region within 5 years of the year worked. A score of 2 (medium-low confidence) indicated that either regional/other state data 6–10 years from the work year were used or that national data within 5 years were used. A score of 1 (low confidence) indicated that the probability was calculated from national data 6–10 years from the work history year. Pesticide use was considered to be unknown for years in which there were no pesticide data that met any of the confidence level criteria.

We calculated probabilities for individual pesticides for years when our confidence score was 3 or 4. Due to the large number of pesticides with low probabilities of use, we present only those pesticides that showed 33% or greater probability of use on the reported crop. If the pesticide was used on multiple crops, we calculated an average probability that was weighted by the days worked with each crop. We also calculated the percentage of the work history days for which work with the crop may have resulted in contact with the specific pesticides (if probability of use was 33% or greater). Several tasks were considered to be unlikely to result in exposure and were not included in the calculation. These included planting apples and general farm work.

To determine if a particular task is likely to result in exposure and to estimate level of exposure, monitoring data are critical. We reviewed the literature to determine if monitoring data were available for the crops–task combinations reported by the two workers.

RESULTS

Agricultural Work Histories

The workers spent an average of 69% of their agricultural work history working with crops or livestock in the seven pilot study states. The number of different crops worked (including livestock) was 30 for California, 28 for Washington, 27 for Texas, 15 for Colorado, 14 for Florida, 14 for Montana, and 10 for Wisconsin. The crops that accounted for 75% of the reported jobs in each of the seven pilot states (hereafter called major crops) are listed in Table I. The number ranged from one for Montana to 10 for California. Fruits and vegetables crops constituted the majority of the crops worked but other major crops included cotton in California and Texas, cattle in Colorado, sugar beets in Colorado and Montana, hops in Washington, and Christmas trees in Wisconsin.

The most commonly performed task varied by crop; however, harvesting was the most frequently reported task for many of the major crops [Table I]. Other major task–crop combinations included thinning peach orchards and sugar beets; pruning grape vines, apple orchards and Christmas trees; weeding/hoeing onions and hops; sorting potatoes; packing carrots; and driving equipment for cotton. Across states, the tasks performed for a particular crop were generally the same; however, the major task for the crop varied somewhat by state. For example, harvesting was the major task reported for grapes in California whereas pruning was the major task reported for Washington and Colorado grapes. The median time spent doing the task ranged from 14 days for harvesting many types of fruits and vegetables to 90 or more days for harvesting onions, sorting potatoes, weeding onions and hops, thinning sugar beets, and working with cattle.

The time span of the work histories also varied by state among our study subjects because a few of the states included retired workers whereas most included only active workers (Table I). The work histories for the major crops started as early as the 1930s in Montana and Texas, in the 1940s for California, in the 1950s for Colorado and Florida, and in the 1960s and 1970s for Washington and Wisconsin, respectively. The median year of work for most crops was in the 1980s, reflecting the large number of active farmworkers in the pilot study.

TABLE I. Major Crops, Tasks, Task Time, and Work History Periods Reported by 162 Migrant Workers in the Seven Pilot Study States

State (number of workers interviewed)	Crop	Number of jobs (% of state total)	Number of tasks	Major task	Median task time (days)	First year	Last year	Median year
California (36)	Grapes	643 (43.7)	8	Harvesting	75	1949	1996	1986
	Peaches	87 (5.9)	5	Thinning	45	1956	1996	1982
	Tomatoes	75 (5.1)	7	Harvesting	75	1949	1996	1982
	Apples	58 (3.9)	4	Pruning	45	1974	1995	1984
	Plums	52 (3.5)	1	Harvesting	14	1957	1995	1984
	Asparagus	48 (3.2)	1	Harvesting	14	1962	1995	1982
	Cotton	44 (3.0)	4	Driving equipment	73	1947	1995	1980
	Broccoli	44 (3.0)	2	Harvesting	14	1962	1996	1982
	Lettuce	43 (2.9)	3	Harvesting	45	1958	1995	1987
	Oranges	41 (2.8)	1	Harvesting	45	1959	1995	1968
Colorado (18)	Potatoes	24 (24.2)	2	Sorting	105	1956	1996	1992
	Onions	16 (16.1)	4	Weeding, hoeing	137	1987	1996	1994
	Sugar beets	14 (14.1)	3	Thinning	105	1956	1996	1962
	Cattle	11 (11.1)	—	NR	349	1989	1996	1994
	Grapes	10 (10.1)	1	Pruning	45	1977	1987	1981
Florida (18)	Oranges	200 (52.2)	3	Harvesting	34	1950	1996	1984
	Strawberries	79 (20.6)	3	Harvesting	73	1978	1996	1988
	Tomatoes	66 (17.2)	3	Harvesting	14	1969	1996	1988
Montana (18)	Sugar beets	394 (80.9)	5	Thinning	44	1936	1996	1966
Texas (18)	Cotton	332 (35.5)	5	Harvesting	45	1936	1995	1974
	Cantaloupe	138 (14.8)	3	Harvesting	75	1936	1995	1969
	Onions	98 (10.5)	5	Harvesting	90	1943	1995	1976
	Corn (sweet)	74 (7.9)	2	Harvesting	44	1936	1993	1953
	Lettuce	63 (6.7)	3	Harvesting	73	1969	1994	1985
Washington (18)	Asparagus	149 (23.5)	4	Harvesting	75	1967	1996	1988
	Apple	135 (21.3)	6	Harvesting	44	1977	1996	1991
	Pears	64 (10.1)	5	Harvesting	14	1985	1996	1993
	Cherries	53 (8.4)	3	Harvesting	14	1977	1996	1992
	Grapes	47 (7.4)	6	Pruning	45	1987	1996	1993
	Hops	31 (4.9)	4	Weeding, hoeing	105	1976	1995	1981
Wisconsin (36)	Christmas trees	82 (39.6)	3	Pruning	45	1986	1996	1993
	Carrots	37 (17.9)	1	Packing	76	1979	1996	1989
	Cucumbers	35 (16.9)	2	Harvesting	75	1983	1996	1995
	Onions	24 (11.6)	2	Weeding	NR	1970	1996	1983

NR, not reported.

Pesticide Use Data for Major Crops

The pesticide use survey data for the major crops are summarized in Table II. From the 1960s through the mid-1970s, only national estimates of specific pesticides used were reported for a few of the major crops, including cotton, livestock, potatoes, apples, and citrus fruits. In the late 1970s, regional or state-specific data on pesticide use were available for some vegetables, fruits, and cotton in the seven pilot states. However, a few of the major vegetable and fruit crops reported in this study were not surveyed: asparagus, broccoli, lettuce, strawberries, and plums.

In the early 1980s, the only data available for the major crops were national estimates of pesticide use for cotton pesticides and livestock insecticides. From 1986 through 1989 state data were available for herbicide use on cotton in California and Texas. From the late 1980s through the 1990s, some pesticide use data were also available for Colorado potatoes and onions, Montana sugar beets, and Wisconsin carrots, cucumbers, onions, and Christmas trees.

TABLE II. Federal and State Pesticide Use Data for Major Crops Reported by Migrant Workers by Decade Worked

State	Crop	1960–69	1970–79	1980–89	1990–97[a]
California[b]	Vegetables				
	Asparagus	—[c]	—	—	1992, 1994, 1996, USDA
	Broccoli				
	Lettuce				
	Tomatoes	—	1979 USDA regional data		1992, 1994, 1996 USDA
	Fruits				
	Apples	1964, 1966 USDA national data	1971 USDA national data; 1978 USDA regional data	—	1993, 1995, 1997 USDA
	Grapes	—	—	—	1993, 1995, 1997 USDA
	Oranges	1964, 1966 USDA national data (reported as all citrus)	1971 USDA national data (all citrus); 1977 USDA data for CA	—	1993, 1995, 1997 USDA
	Peaches	—	1978 USDA regional data	—	1993, 1995, 1997 USDA
	Plums	—	—	—	1993, 1995, 1997 USDA
	Cotton	1964, 1966 USDA national data	1971, 1976 USDA national data; 1979 USDA regional data	1982 USDA national data; 1986–1989 USDA data for CA, herbicides	1990–97 USDA
Colorado	Cattle	1964, 1966 USDA national data	1971, 1976 USDA national data	1982 USDA national data	—
	Grapes	—	—	—	—
	Onions	—	1979 USDA regional data	1989 Colorado state survey	1992 Colorado survey
	Potatoes	1964, 1966 USDA national data	1971 USDA national data; 1979 USDA regional data	1988–89 USDA data for Colorado	1992–1995 USDA
	Sugar beets	1966 USDA national data	1971 USDA national data; 1978 Minnesota survey	1987 Montana survey —	1992 Colorado survey
Florida	Oranges	1964, 1966 USDA national data (reported as all citrus)	1971 USDA national data (citrus) 1977 USDA state data	—	1991, 1993, 1995, 1997 USDA
	Strawberries	—	—	—	1990,1992, 1994, 1996 USDA; 1994–97 Florida NASS reports
	Tomatoes	—	1979 USDA regional data	—	1990,1992, 1994, 1996 USDA
Montana	Sugar beets	1966 USDA national data	1978 Minnesota survey	1987 Montana survey	1992, 1999 Montana survey
Texas	Cantaloupes	—	1979 USDA regional data	—	1990, 1992, 1994, 1996 USDA
	Corn (sweet)	—	1979 USDA regional data	—	1990, 1994 USDA
	Cotton	1964, 1966. USDA national data	1971, 1976 USDA national data; 1979 USDA regional data	1982 USDA national data; 1986–1989 USDA data for CA (herbicides only)	1990–97 USDA
	Lettuce	—	—	—	1990, 1992 USDA
	Onions	—	1979 USDA regional data	—	1990, 1992, 1994, 1996 USDA
Washington	Apples	1964, 1966 USDA national data	1971 USDA national data; 1978 USDA regional data	—	1991, 1993, 1995, 1997 USDA

TABLE II. *Continued*

State	Crop	1960–69	1970–79	1980–89	1990–97[a]
	Asparagus	—	—	—	1992, 1994, 1996 USDA
	Cherries	—	1978 USDA regional data	—	1991, 1993, 1995, 1997 USDA
	Grapes	—	—	—	1991, 1993, 1995, 1997 USDA
	Hops	—	—	—	—
	Pears	—	1978 USDA regional data	—	1991, 1993, 1995, 1997 USDA
Wisconsin	Carrots	—	1979 USDA regional data	1985 Wisconsin survey	1992, 1994, 1996 USDA; 1990, 1996 Wisconsin surveys
	Cucumbers	—	1979 USDA regional data —	—	1992, 1994, 1996 USDA; 1996 Wisconsin survey
	Onions	—	1979 USDA regional data	—	1992, 1994 USDA; 1992, 1996 Wisconsin survey
	Christmas trees	—	—	—	1992 Wisconsin survey

[a] All reports had state-specific data for the crop unless noted otherwise.
[b] California state data for restricted use pesticides were available from 1970 onwards; data for all pesticides and the location of use was available beginning in 1990.
[c] No data available.

Beginning in 1990, state-specific information on pesticide use was available for most of the vegetable and fruit crops reported in this study. Survey data for states that neighbor the pilot states included a sugar beet survey in Minnesota [Minnesota Crop and Livestock Reporting Service, 1980] that could be used to identify possible pesticide use on this crop in Colorado and Montana in the late 1970s.

Pesticide Use Probabilities

In Table III we summarize the work histories for two workers and present pesticide use probabilities by general type of pesticide. The first worker had jobs in Washington planting, pruning, thinning, and harvesting apples in the 1980s, and planting and thinning apples, sorting corn, pruning grapes, and sorting onions in the 1990s. The second worker's earliest agricultural jobs were in Mexico harvesting sweet corn in the 1930s. Later work included weeding/hoeing cotton in Texas in the 1940s and 1950s, and weeding, thinning, and harvesting sugar beets in Montana from the 1950s through the 1980s.

Probabilities of pesticide use for the crops reported by the first worker were calculated using Washington data from USDA surveys for fruits in 1991 and 1995, and vegetables in 1992 and 1996. For the second worker, national estimates of herbicide and insecticide use on cotton were available for 1952 [Osteen and Szmedra, 1989]. Regional estimates of herbicide, insecticide, and fungicide use on sugar beets in the mountain states from a 1966 USDA survey were used to calculate probabilities from 1956 through 1971, whereas data from a 1978 Minnesota survey were used for the years 1972 to 1980.

The estimated probability of insecticide use on apples in Washington was greater than 90% in the 1980s and 1990s. Other types of pesticides (including growth regulators and defoliants) were also used on a high percentage of apple acreage (70–89%). Fungicide use on apples increased from the early to mid-1990s. Herbicide use was high for corn, grapes, and onions, and insecticide use was high for corn and onions. Fungicides were used on a high percentage of onion acreage. The probability of insecticide use on cotton in the late 1940s to early 1950s was about 50%, whereas herbicide use was uncommon. Pesticide use probabilities for sugar beets were estimated to be less than 40% from the late 1950s through the early 1970s; herbicide use increased during the 1970s.

Individual pesticide probabilities could not be calculated before the 1960s because of the absence of survey data. However, the pesticides available during the 1930s through the 1950s were quite limited so it is possible to describe the pesticides that were likely to have been applied to crops reported by Worker Two. In the 1930s, inorganic insecticides were the major pesticides available for agricultural use [Ennis and McClellan, 1964; Hall, 1964].

TABLE III. Work Histories for Two Workers and Crop-Specific Probabilities of Pesticide Use by General Type of Pesticide

				Probability Cagegory[a]				
State	Year (s)	Crop	Task	H	I	F	O	Confidence[b]
Worker One								
WA	1983–85	Apples	Harvesting, pruning, thinning, planting	3	5	3	4	2
WA	1987–88	Apples	Thinning, planting, pruning, harvesting	3	5	3	4	4
WA	1990	Apples	Thinning, planting, general farming	3	5	3	4	4
WA	1990–91	Corn	Sorting	4	4	1	1	4
WA	1992	Grapes	Pruning	4	2	2	NR	4
WA	1996	Apples	Thinning	3	5	4	4	4
WA	1996	Onions	Sorting	5	5	4	3	4
Worker Two								
Mexico	1936	Corn	Harvesting	—[c]	—	—	—	
TX	1945–49	Cotton	Weeding/hoeing	1	3	NR	NR	1
TX	1950–51	Cotton	Weeding/hoeing	1	3	NR	NR	2
MT	1951–55	Sugar beets	Weed/hoeing, thinning, harvesting	—[d]	—	—	—	
MT	1956–60	Sugar beets	Weed/hoeing, thinning, harvesting	2	2	1	NR	2
MT	1961–71	Sugar beets	Weeding/hoeing, thinning, harvesting	2	2	1	NR	3
MT	1972[e]	Sugar beets	Weeding/hoeing, thinning, harvesting	4	2	2	NR	2
MT	1973–80[e]	Sugar beets	Weeding/hoeing, thinning, harvesting	4	2	2	NR	3

[a] H, herbicide; I, insecticide; F, fungicide; O, other chemical. Probability categories: 1, $\leq$10%; 2, 10–39%; 3, 40–69%; 4, 70–89%; 5 $\geq$ 90%.
[b] Confidence in probability estimate: 4, data for same state within 5 years; 3, data for region or nearby state within 5 years; 2, national data within 5 years or state or regional data within 6–10 years; 1, national data within 6–10 years.
NR, not reported.
[c] No pesticide use survey data available.
[d] No pesticide use data that met the minimum confidence criteria.
[e] Probabilities of use on sugar beets for 1972–1980 were the percent of total acres treated instead of acres planted.

Insecticide use on cotton was well established by the early 1950s [Osteen and Szmedra, 1989] due to the significant damage caused by cotton pests, particularly the boll weevil. During the late 1940s through the mid-1950s, organochlorine insecticides were used to control cotton pests. The earliest pesticides in this class of insecticide were Dichloro-Diphenyl-Trichloroethane (DDT), lindane (BHC), and toxaphene; later others were introduced including aldrin, dieldrin, endrin, heptachlor, Strobane, and Tetrachloro-Diphenylethane (TDE) [National Academy of Sciences, 1975]. Pesticide use information was not available for sugar beets in the early 1950s, but estimates from the 1966 USDA survey for the mountain region indicated that insecticides, herbicides, and fungicides were used on 20%, 28%, and 1% of acres, respectively. Use in previous years was likely to have been less. The major herbicides reported for sugar beets in 1966 were the carbamates and a category of "other" organic herbicides that excluded petroleum, the triazines, benzoic, phenoxy, phenyl urea, dinitro or amide herbicides. Use data for individual insecticides and fungicides were not reported for sugar beets.

In Table IV, we present the pesticide probabilities for seleted years in which probabilities could be calculated with a medium-high or high confidence level. The list of pesticides includes only those that were used on 33% or more of acres. Work with apples accounted for 40% of the workdays during 1990–1996 for Worker One. However, half of those days involved planting and general farmwork, tasks that we assumed had a low probability of exposure to pesticides. The insecticide azinphosmethyl was used on 90% or more of apple acres and an additional 11 pesticides had probabilities of 33% or higher. For onions, sweet corn, and grapes, the number of pesticides with probabilities of 33% or higher was nine, two, and one, respectively. The specific pesticides used differed across the four crops, with the exception of the herbicide glyphosate that was used on apples, grapes, and onions. As a result, we estimated that 62% of the first worker's workdays in the 1990s entailed probable exposure to glyphosate.

Worker Two performed various tasks for sugar beets during 1973–1980. We considered harvesting to involve little pesticide exposure, therefore 67% of the days worked had potential exposure to pesticides. Only one herbicide and one insecticide were used on 33% or more of sugar beets acreage during this period.

Of the tasks reported by both workers, thinning apples was the only crop–task combination for which we found exposure monitoring data. Five studies evaluated dermal

TABLE IV. Crop-Specific Probabilities of Pesticide Use for Individual Pesticides Calculated for Selected Time Periods From Two Workers' Histories*

	Probability category				Mean probability (weighted by days worked)	Percent of days worked with potential exposure[a]
	Apples	Grapes	Onions	Corn		
Worker One (worked 284 days during 1990–1996)						
Pesticide use 1990–1996						
Herbicides						
Atrazine				3	3	18
Glyphosate	2,3[b]	3	3		3	62
Oxyflurofen			4		4	16
Bromoxynil			3		3	16
DCPA			3		3	16
Fluazifop *p*-butyl			3		3	16
Pendimethalin			3		3	16
Lambdacyhalothrin			3		3	16
Insecticides						
Azinphos-methyl	5				5	20
Carbaryl	3				3	20
Chlorpyrifos	3, 4[b]				3	20
Endosulfan	2				2	20
Esfenvalerate				3	3	18
Petroleum distillate	4				4	20
Phosphamidon	4				4	20
Fungicides						
Mancozeb		2			2	16
Myclobutanil	3				3	5
Ziram	2				2	5
Other						
Cytokinins	3				3	20
NAA	3				3	20
Gibberellic acid	3				3	20
Maleic hydrazide		3			3	16
Worker Two (worked 336 days during 1973–1980)						
	Sugarbeets					
Pesticide use 1973–1980						
Herbicides						
EPTC, Eptam	3				3	67
Insecticides						
Aldicarb	2				2	67

*Probabilities for specific pesticides are listed if the confidence level was 4 or 3 (data for same state, region, or nearby state within 5 years of the work history year) and if the probability was 33% or greater: 2, 33–39%; 3, 40–69%; 4, 70–89%; 5, $>$90%.

[a][(Sum of all days worked with possible exposure)/(Days worked on crops in decade)] $\times$ 100; Planting and general farmwork with apples, and harvesting sugarbeets were not counted in days with possible exposure.

[b]Probability first half of decade, probability second half of decade.

exposures for this task. In two studies, hand exposure was measured [Fenske et al., 1989, 1999]. Mean exposure levels for phosalone (an organophosphate insecticide) were 8.6 mg/h (duration 2 h, 1 or 2 days after application [n = 7]) [Davis et al., 1982] and 3.3 mg/h (duration 2 h, 1–9 days after application [n = 22] [Davis et al., 1983]. Levels of carbaryl among workers with detectable levels (11 of 17) were 0.6 mg/h (duration $<$15 min, 0–52 days after application) [Maitlen et al., 1982].

To estimate if a task is likely to have measurable exposure to pesticides, exposure monitoring studies are critical. Such data are sparse as determined by Stewart et al., (this issue; Table I). In the absence of exposure monitoring studies, information on the timing of the task in relation to pesticide application and the chemical properties of the pesticide could be used to determine if the task was likely to incur exposure to pesticides [Stewart et al., 2001, this issue]. Information on pest management practices can be obtained from State Extension Service reports or by talking with State Extension Agents. The USDA's crop profile database currently under development will be a useful resource for current cultivation and pesticide use practices (USDA Office of Pest Management website). Chemical property data for many agricultural pesticides can be found on the Internet (Extoxnet website).

DISCUSSION

We determined the feasibility of identifying probable pesticide exposures for migrant workers based on work history information on the crops, tasks, locations, and time periods worked. Workers usually cannot report specific pesticides used themselves as indicated by this study [Zahm et al., 2001, this issue] and others [Mentzer and Villaba, 1988] nor can they report the pesticides used in their vicinity [Mentzer and Villaba, 1988]. However, they can provide detailed work history information [Zahm et al., 2001, this issue]. Crop-specific pesticide use data can be linked to work histories to identify the specific pesticides to which workers may have been exposed.

For the major crops reported by workers in this study, we summarized the pesticide use data by state, crop, and year. We found numerous gaps in the data. Many individuals worked with crops in the 1930s, 1940s, and 1950s for which no survey information is available on the use of specific pesticides. Agricultural Extension reports on recommended pesticide use were available for some states, thus providing some data on the potential exposures when survey data were not available. This type of information and summary data on early pesticide use [Ennis amd McClellan, 1964; Hall, 1964] may be most useful for estimating exposures in early decades when the number of pesticides available was relatively small.

The earliest comprehensive pesticide use data is from the mid-1960s. However, these reports included only national estimates of use for a limited number of crops. For most of the vegetable and fruit crops, the earliest usage data were regional estimates in the late 1970s. In the 1980s, there were no federal surveys of pesticide use for fruits and vegetables and state surveys were limited. As of 1990, the data for fruits and vegetables improved considerably. The USDA began alternating year surveys of pesticide use in the major producing states and California expanded its pesticide use reporting system to include all agricultural pesticides. For the field crops, including cotton and potatoes, there were annual state data beginning in the late 1980s. However, in spite of the improvements in the national usage data in the 1990s, the USDA surveys do not include some of the major crops reported in this study including sugar beets, Christmas trees, hops, and cattle.

National and regional estimates of pesticide use are likely to be less accurate than estimates based on state-specific data because of the variation in pesticide use due to weather conditions, pest infestations, pest management practices, cost, and other factors. However, even when state pesticide use data are available they are likely to have serious limitations due to local variations in pest problems and pest management practices. For example, large states such as California and Texas have several agricultural regions with different climatic conditions, pest problems, and other factors. As of 1990 in California, all agricultural pesticide use is reported by the specific location (Public Land Survey section) and date of the application (California Department of Pesticide Regulation website). The California pesticide use data is the most comprehensive and detailed of any state, thus making it the most useful database for reconstructing probable pesticide exposures among farmworkers.

We calculated probabilities that a pesticide was used on a crop by dividing the acres treated by the total acres of the crop. We assigned a level of confidence for each probability estimate based on the degree of extrapolation from the state and year. Such a designation allows exclusion of the workers with the least reliable estimates in an epidemiologic analysis.

The probability level we calculated is not exactly equivalent to the probability of exposure, because exposure is affected by other factors in addition to pesticide use. Rather, the probability level is an estimate of the likelihood that a crop was ever treated with a particular pesticide and thus it can be considered a relative ranking for the specific pesticides to be considered further in the exposure assessment. Over a work year, individuals will work in multiple fields and may work on multiple farms, thus increasing the chances that they were exposed to pesticides with high probabilities of use.

The level or intensity of pesticide exposure is affected by a number of factors, called exposure determinants. Few studies have evaluated the effect of exposure determinants under controlled conditions [Stewart et al., 2001, this issue]. The type of task performed determines the amount of contact an individual will have with the treated soil or plant foliage and is an important determinant of exposure, because the primary route of exposure is through the skin for most workers [Fenske, 1997]. Exposure monitoring studies that measure pesticide residues on the clothing and skin of farmworkers performing various tasks are essential in order to determine whether a worker is exposed and also the level of exposure. However, for the large majority of pesticide–crop–task combinations no exposure studies have been conducted.

APPENDIX. USDA Pesticide Use Surveys, 1964–1997

Year of survey	Crops reported	States included	Description of data	Reference
1964, 1966, 1971	Field crops (cotton, tobacco, alfalfa, other hay, corn, wheat, sorghum, rice, other grain, soybeans, peanuts, sugar beets [1966], pasture/rangeland), potatoes, other vegetables, fruits (citrus, apples, other), livestock insecticides	48 states	National estimates of acre treatment and pounds of active ingredient applied by crop or crop category for herbicides, insecticides, fungicides, other (miticides, fumigants, defoliants/desiccants, plant growth regulators)	Eichers et al.,1968,1970, 1974, USDA 1982
1976	Field crops (cotton, tobacco, alfalfa, other hay, corn, wheat, sorghum, rice, other grain, soybeans, peanuts, pasture/rangeland), livestock insecticides	48 states	National estimates including acres treatments and pounds applied for herbicides, insecticides, fumigants, other pesticides	Eichers et al., 1978
1977	Citrus fruits	Arizona, California, Florida, Texas	State estimates (Arizona and California were combined) of acres treated, application rates, pounds applied for herbicides, insectisides, fungicides, other	Haydu, 1981
1978	Deciduous fruits: apples, peaches, pears, tart cherries	Major producing states except California	Regional estimates of acres treated, application rates, pounds applied for herbicides, insecticides, fungicides, other	Webb, 1981
1979	Vegetable crops including cabbage, cantaloupe, carrots, celery, cucumber, onions, sweet corn, tomatoes, others	18 major producing state except California	Regional estimates of acres treated, application rates, number of times applied, pounds applied for herbicides, insecticides, fungicides, other	Ferguson, 1984
1979	Grapes	Pennsylvania, New York	State estimates of acres treated, application rates, number of times applied, pounds applied for herbicides, insecticides, fungicides, other	Fluke et al., 1982
1979	Fall potatoes	11 major producing states	Regional estimates of acres treated, application rates, number of times applied, pounds applied for herbicides, insecticides, fungicides	Parks, 1983
1979	Cotton	12 major producing states	Regional estimates acres treated, application rates, number of times applied, pounds applied	McDowell et al., 1982; Rich, 1982
1982	Field crops including corn, cotton, peanuts, sorghum, soybeans, tobacco, barley, oats, rice, wheat, alfalfa, other hay, and pasture; livestock insecticides	33 states	National estimates of acres treated one or more times, application rate, pounds applied for herbicides, insecticides, fungicides, other pesticides	USDA, 1982; Duffy, 1983
1986, 1987	Field crops: corn, cotton, soybeans	Major producing states	State estimates of acres treated, pounds applied, application rates for herbicides, insecticide, fungicides, other pesticides; only herbicide use for cotton	USDA Outlook reports
1988 through 1997	Field crops: corn, cotton, peanuts,[a] potatoes, rice, sorghum,[a] soybeans, tobacco,[b] wheat	Major producing states	State estimates of acres treated,[c] pounds applied, application rates for herbicides, insecticides, fungicides, other pesticides; herbicide use only for cotton in 1988–89	USDA 1989–1998
1990	Vegetables: asparagus, broccoli, cabbage, carrots, cauliflower, celery, garlic, green peppers, lettuce, lima beans, onions, sweet corn, tomatoes, strawberries, melons (cantaloupe, honeydew, watermelon)	Major producing states except California	State estimates of acres treated, pounds applied, application rates for herbicides, insecticides, fungicides, other pesticides	USDA 1991
1991	Fruits: apples, avocado, cherries, grapefruit, grapes, oranges, peaches, pears, plums; nuts; berries	12 major producing states except California	State estimates of acres treated, pounds applied, application rates for herbicides, insecticides, fungicides, other pesticides	USDA 1992

APPENDIX. *Continued*

Year of survey	Crops reported	States included	Description of data	Reference
1992	Vegetables: asparagus, broccoli, carrots, cucumbers, green peppers, lettuce, onions, sweet corn, tomatoes, strawberries, melons	14 major producing states	State estimates of acres treated, pounds applied, application rates for herbicides, insecticides, fungicides, other pesticides	USDA 1993
1994, 1996	Vegetables: asparagus, broccoli, cabbage, carrots, cauliflower, celery, cucumbers, eggplant, green peas, green pepper, lettuce, lima beans, onion, snapbeans, spinach, sweet corn, tomatoes, strawberries, melons[d]	14 major producing states	State estimates of acres treated, pounds applied, application rates for herbicides, insecticides, fungicides, other pesticides	USDA 1995, 1997
1993, 1995, 1997	Fruits: apples, apricot, avocado, cherries, dates, figs, grapefruit, grapes, kiwi, nectarine, olives, oranges, peaches, pears, plums; nuts; berries	Nine states in 1993, 1995;11 states in 1997	State estimates of acres treated, pounds applied, application rates for herbicides, insecticides, fungicides, other pesticides	USDA 1994, 1996, 1998

[a] Peanuts and sorghum were included in the 1991 survey only.
[b] Tobacco was included in the 1996 survey only.
[c] 1988 and 1989 surveys obtained only acres treated.
[d] Data was not reported separately for cantaloupe in the 1996 report.

In the absence of exposure monitoring studies, another approach to estimating the level of exposure to pesticides is needed. Stewart et al. [2001, this issue] describe an approach whereby information on the pesticide application rate, half-life, duration, task, and protective clothing are used to determine relative exposure levels among workers performing pesticide-exposed tasks. The approach appeared to work well when compared with limited exposure monitoring data; however, the authors concluded that the approach needed to be evaluated further before any conclusions could be made about its utility.

Migrant farmworkers and their families may have exposure to pesticides other than through their work with crops. Worker housing is usually located near crop fields and within the typical range of pesticide drift from spraying operations [Chester and Ward, 1984; Seiber and Woodrow, 1981]. Pesticides used on apples have been detected in house dust samples from farmworkers homes [Simcox et al., 1995] and in serum from farmworkers children [Loewenhertz et al., 1997]. Exposures in the home appear to be due to residues carried home on clothing and the proximity of the homes to crop fields [Simcox et al., 1995; Loewenhertz et al., 1997]. Farmworker exposures can be further exacerbated if there is a lack of clean water for washing.

In summary, the available data on pesticide use indicate that for recent years it is feasible to identify the pesticides used on most of the crops worked by migrant and seasonal farmworkers. These data, together with other information can be used to estimate the probability that a farmworker was exposed by their work with a particular crop. This approach has many limitations and errors that cannot be easily quantified. The survey methods and sample size varied over time and across states, and the data collected were not validated. State estimates of pesticide use do not account for regional and local variability in pesticide use practices. Pesticide use reporting systems such as the one in California where agricultural pesticide use is reported at a scale of one square mile would alleviate many of the uncertainties of statewide estimates.

Our approach to estimating probable pesticide exposures among farmworkers is an important step towards evaluating the health effects of general classes of pesticides and widely used specific pesticides among this occupational group. The general lack of knowledge among farmworkers about their specific pesticide exposures precludes approaches used in studies of farmers and other pesticide applicators [Blair et al., 1997; Cantor et al., 1992; Zahm et al., 1990]. Another approach is to evaluate risk by duration of farm work, duration of performing a particular crop–task, or some other surrogate of exposure. Whereas these surrogates may accurately reflect the analytical variable (e.g., duration of being a migrant farmworker), they are likely to result in more misclassification with respect to pesticide exposures than the approach we present.

A similar approach to estimating probabilities of exposure to specific chemicals has been used by industrial hygienists in population-based case-control studies. Study participants usually cannot provide information about their specific exposures, so industrial hygienists use their knowledge about specific jobs to estimate exposures from work histories. In these studies, the exposure estimation process has been described either poorly or not at all [Stewart and Stewart, 1994; Stewart, 1999]. Documentation of the data used to estimate exposures is a crucial component of an accurate and reproducible exposure assessment.

Our approach attempts to account for the variation in pesticide use across regions and over time. When the data are available, workers can be grouped for analysis by their estimated probability of exposure to general types of pesticides, chemical classes, or individual pesticides. However, we caution that the limited pesticide use data before the 1990s for many crops will affect the quality of the exposure assessment for most workers in studies of chronic health outcomes. Further, we caution that statewide estimates of use may not be adequate for accurately identifying specific pesticide exposures due to local variations in use of individual chemicals within the general types of pesticides (insecticides, herbicides, etc.)

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